FESHM 5062.1: LASERS

Revision History

Author	Description of Change	Revision No. & Date
Matthew Quinn	Added a technical appendix on laser pointers, laser sign/label artwork, and a reference to the FDA laser standard. Chapter reformatted to fit the standard layout scheme.	September 2011

TABLE OF CONTENTS

1.0 INTRODUCTION

There are many kinds of lasers and numerous applications. In addition, the relationships between emitted radiations and harmful effects can be complicated. In order to simplify the implementation of control measures, laser radiation hazards are rated on a scale from class 1 (safe) to class 4 (dangerous). It is unlikely that a hazard class 1, 2, or 3a laser would cause an inadvertent injury. On the other hand, hazard class 3b and 4 lasers have a significant potential for causing accidental injuries. Not surprisingly, most control measures are associated with these higher class systems.

At Fermilab, class 3b and class 4 laser systems are primarily utilized in scientific applications. For example, class 3b nitrogen lasers are used as a source of pulsed ultraviolet radiation for calibrating scintillation detectors. Class 4 Nd:YAG (and similar) lasers are also used in material applications and for direct photon-particle interactions. Lasers used in commonly-encountered commercial applications such as bar code scanners, pointers, alignment systems, CD/DVD systems, and fiber optic communication systems tend to be class 2 or class 3a diode lasers.

2.0 DEFINITIONS

<u>Diffuse viewing</u> - Refers to looking at scattered radiation such as occurs during many alignment activities.

<u>Failsafe interlock</u> – An interlock where the failure of a single interlock component will cause the system to go into, or remain in, a safe mode.

<u>Interlocked</u> – With regard to a laser radiation enclosure, “interlocked” means that laser radiation levels are automatically reduced to harmless levels when a protective enclosure is opened. If the interlock is not failsafe, an appropriate warning label must also be attached to the enclosure.

<u>Intrabeam viewing</u> - Refers to direct or specularly-reflected eye exposure as might occur in an accident.

<u>Laser Safety Committee</u> – A group that meets regularly to review Fermilab’s laser safety activities. Membership includes the laser safety officer, laser safety representatives, and division/section ES&H personnel where laser activities presenting significant risk are taking place. This mainly involves activities with hazard class 4 lasers.

<u>Laser Safety Representative</u> (LSR) – An individual who can represent a laser operation with regard to its ES&H aspects. This is typically the person responsible for day-to-day management of the laser system.

<u>Laser Safety Officer</u> (LSO) – The individual who assures that laser hazards are adequately monitored, evaluated, and controlled.

Locked – With regard to a laser radiation enclosure, "locked" means that a tool is required to gain access to the laser beam and an appropriate warning label has been attached to the enclosure.

Maximum Permissible Exposure (MPE) – The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. The MPE is a complex function of wavelength, modulation and exposure duration.

Nominal Hazard Zone (NHZ) – The space within which the level of direct, reflected, or scattered radiation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

Public – For the purposes of laser safety, individuals whose access to laser radiation is not explicitly controlled by the laser operator. For public displays, there must be a lateral distance of at least 2.5 m between hazardous levels of laser radiation and locations where members of the public are permitted. The minimum vertical distance between hazardous levels of laser radiation and surfaces upon which members of the public may stand is 6.0 m. The vertical distance can be reduced to 3.0 m if the laser system is continuously controlled by an experienced trained operator who maintains constant surveillance of the laser display and can terminate the laser emission in the event of a problem.

Spectator – For the purposes of laser safety, an individual whose access to laser radiation is explicitly controlled by the laser operator.

Tool - With regard to a laser radiation enclosure, the requirement for a "tool," when used in conjunction with a warning label, greatly reduces the likelihood of inadvertent access to hazardous laser radiation levels. A key to a lock is considered a tool for the purposes of this chapter.

3.0 RESPONSIBLILITIES

3.1 Laser Safety Officer (LSO)

The LSO plays a Lab-wide consultative and oversight role in the evaluation and control of laser hazards including system classification, procedures, protective equipment, warning systems, facilities, training, and medical surveillance.

3.2 Laser Safety Committee

The Laser Safety Committee plays a role in communication, consultation, and oversight for laser hazards associated with planned and active laser operations. This committee also provides a venue for participants to share expertise and equipment. The meeting frequency is adjusted to accommodate the pace of class 4 laser activities, typically quarterly to monthly.

4.0 PROCEDURES

Below is a summary of Fermilab's laser safety requirements. Precautions for beam hazards are presented according to hazard class and are based on the latest version of ANSI Z136.1. Though general in nature, this information provides a solid basis for understanding the required actions. Exhaustive guidance is available in the applicable standard, some of which is presented in subsequent pages of this chapter.

4.1 Hazard class 1

4.1.1 Description - Any laser that requires more than eight hours of direct eye exposure to produce an injury. Considered harmless. The maximum output of a class 1 visible wavelength CW laser ranges from 40 to 400 μW, depending on wavelength.

4.1.2 Precautions - Usually none. However problems may arise if the laser is modified in a way that may increase its output or there is an embedded laser that has a higher hazard class. If these are encountered, follow the precautions for the appropriate hazard class.

4.2 Hazard class 2

4.2.1 Description **-** A laser that emits radiation in the visible portion of the spectrum and requires more than 0.25 seconds of direct eye exposure to produce a retinal lesion. Since the bright light emitted from such a device triggers a "blink reflex", and most people can blink within 0.15 seconds, an injury can only occur by forcibly staring into the beam. Considered low hazard. The body has a mechanism to protect itself and significant retinal damage requires prolonged staring. The maximum output of a class 2 CW laser is 1 mW. The wavelength of the radiation must be within the visible portion of the spectrum (0.4 to 0.7 μm).

4.2.2 Precautions - Do not stare into the beam. Do not point the laser in the direction of other people or shiny objects. Precautions for public displays apply (see definitions). As with hazard class 1 lasers, problems may arise if the laser is modified in a way that may increase its output or there is an embedded laser that has a higher hazard class. If these are encountered, follow the precautions for the appropriate hazard class.

4.3 Hazard class 3a

4.3.1 Description - A laser that has 1 to 5 times the output of a class 1 laser in the invisible portions of the spectrum (<0.4 μm or >0.7 μm), or 1 to 5 times the output of a class 2 laser at visible wavelengths (0.4 to 0.7 μm). In addition, the applicable exposure limit must not be exceeded, e.g., due to large beam diameter. For example, a class 3a visible wavelength CW laser can have an output of 1-5 mW, as long as the irradiance does not exceed 2.5 mW/cm^2. Considered a modest hazard.

4.3.2 Precautions - Do not stare at the beam or view directly with optical instruments. Do not point the laser in the direction of other people or shiny objects. Precautions for public displays apply (see definitions). As with hazard class 1 lasers, problems may arise if the laser is modified in a way that may increase its output or there is an embedded laser that has a higher hazard class. If these are encountered, follow the precautions for the appropriate hazard class.

4.4 Hazard class 3b

4.4.1 Description - Any laser that exceeds hazard class 3a, but less than class 4. At visible and infrared wavelengths (>0.4 μm), a 3b laser can cause eye injury within the time it takes to blink. This applies to the direct beam or a beam that is reflected from a specular surface. A class 3b visible wavelength laser has an output of 5 to 500 mW. UV lasers (<0.4 μm) have a relatively lower threshold for hazard class 3b - 0.1 to 10 μW. Consequently, much longer exposures are required to produce an injury near this threshold. A class 3b laser is considered hazardous.

4.4.2 Precautions

- Avoid eye exposure to the direct or reflected beam.
- The Laser Safety Officer and any personnel deemed appropriate by the division/section responsible for the operation of the laser should be notified prior to operation.
- Laser training is required for persons who may be exposed to the beam while operating, maintaining, or servicing the laser. Training requests, schedules, and sign-ups are accessible in electronic form via TRAIN at the Fermilab ES&H Section website.
- A special laser eye exam is required for all persons who will operate, maintain, or service the laser. This exam is conducted at an offsite eye clinic. Contact Fermilab's Medical Department at X3232 to schedule an appointment. An exam is required (1) prior to initial participation, (2) following a suspected laser eye injury, and (3) upon termination from work at Fermilab.
- Try to reduce the hazard class by enclosing the beam path, especially for extended/repeated operations in a single location. Enclosure is typically in the best interest of the laser operator since it simplifies safety requirements and reduces the likelihood of damage to the laser set up. Enclosures must be interlocked or locked to prevent inadvertent exposure.
- Establish a controlled area during periods of unenclosed operation. Spectators should not be permitted within the controlled area unless (1) approval has been obtained from the laser operator, (2) the degree of hazard and avoidance procedures have been explained to them, and (3) appropriate protection measures have been taken. Precautions for public displays apply (see definitions).
- Wearing of appropriate laser eye protection is recommended, but not required.
- Post signs during periods of unenclosed operation.
- Unattended operation of an unenclosed system requires interlock access control and LSO approval.
- Exercise special care (1) during alignment, (2) when using invisible beams, and (3) where people who are not involved with the operation can be exposed to the beam.
- Initial laser system installation or subsequent modification, including changes in usage or location must be brought to the attention of your division/section ES&H organization.

4.5 Hazard class 4

4.5.1 Description - Any laser where diffusely scattered radiation can cause eye injury within 0.25 seconds. In other words, radiation scattered from a rough surface can cause eye damage within the time it takes to blink. Additionally, depending on output characteristics, class 4 lasers can damage skin, ignite fires, and thermally decompose irradiated materials. A class 4 laser presents a significant hazard that must always be treated with great care. A continuous wave laser of any wavelength with an output exceeding 0.5 W is considered to be class 4.

4.5.2 Precautions

- Avoid eye and skin exposure to the direct or scattered beam.
- Operation requires the prior signature approval of the Laser Safety Officer and any other personnel deemed appropriate by the division/section responsible for the operation of the laser. This is typically accomplished via review and approval of written safety operating procedures that are required in any case.
- Laser training is required for persons who may be exposed to the beam while operating, maintaining, or servicing the laser. Training requests, schedules, and sign-ups are accessible in electronic form via TRAIN at the Fermilab ES&H Section website.
- A special laser eye exam is required for all persons who will operate, maintain, or service the laser. This exam is conducted at an offsite eye clinic. Contact Fermilab's Medical Department at X3232 to schedule an appointment. An exam is required (1) prior to initial participation, (2) following a suspected laser eye injury, and (3) upon termination from work at Fermilab.
- Make every effort to reduce the hazard class by enclosing the beam path, especially for extended/repeated operations in a single location. Enclosure is typically in the best interest of the laser operator since it simplifies safety requirements and reduces the likelihood of damage to the laser set up. Enclosures must be interlocked or locked to prevent inadvertent exposure.
- Establish a controlled area during periods of unenclosed operation. Spectators must not be permitted within the controlled area unless (1) approval has been obtained from the laser operator, (2) the degree of hazard and avoidance procedures have been explained to them, and (3) appropriate protection measures have been taken. Precautions for public displays apply (see definitions).
- Use an audible or visual start up warning to alert others that the laser will be activated. A laser activation warning light is required outside the entrance to each class 4 laser room. The light is illuminated whenever the laser is in use.
- ALWAYS wear appropriate laser eye protection within the controlled area during periods of unenclosed operation. This is a critical precaution. Scattering of the beam from any surface may be able to produce an eye injury within the time you can blink.
- Post signs during periods of unenclosed operation.
- Unattended operation of an unenclosed system requires interlock access control and LSO approval. Exercise special care (1) during alignment, (2) when using invisible beams, and (3) where people who are not involved with the operation can be exposed to the beam.
- Initial laser system installation or subsequent modification, including changes in usage or location must be brought to the attention of your division/section ES&H organization.

4.6 Non-beam hazards

Non-beam hazards are those that do not result from exposure to a laser beam. These include the following:

- Laser components (power supplies)
- Materials used to generate the laser beam (gases, dyes, solvents)
- Materials exposed to the beam (fires, thermal decomposition products)
- Laser environment (mechanical hazards, confined spaces)

Non-beam hazards must be considered in the use of lasers. Guidance on these hazards can be found elsewhere in this manual, in the applicable standard, from your division/section ES&H organization, or the LSO.

5.0 REFERENCES

ANSI Z136.1-2000 – American National Standard for the Safe Use of Lasers
Although ANSI has published subsequent versions of this standard, DOE contractors are required to comply with the version that was published in 2000. See the DOE Worker Safety and Health Rule (10 CFR 851.27) for the statement of this requirement.

21 CFR 1910 – FDA Performance Standards for Light-Emitting Products
http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=1040.10
Section 1910.10 pertains to laser products.

6.0 TECHNICAL APPENDICES

6.1 Laser safety eyewear

Laser protective eyewear is required for unenclosed operation of hazard class 4 systems and recommended for unenclosed operation of hazard class 3b systems. The eyewear must match the characteristics of the laser radiation; in particular, the optical density must be sufficient at the wavelength of interest his information must be marked on the eyewear. Note that the optical density of some materials can decrease for very short pulses ($\leq 10^{-15}$ s). If working with very short pulses, you should verify that the eyewear will perform as expected. Finally, the Visible Light Transmission (VLT) of laser protective eyewear should be at least 20% to assure adequate visibility,

The optical density is calculated as follows.

$$D_\lambda = \log_{10}\left[\frac{H_p}{MPE}\right]$$

D_λ = optical density @ wavelength λ
H_p = potential eye exposure
MPE = Maximum Permissible Exposure

H_p and MPE have the same units.

Actual/Expected exposure durations should be used whenever possible. In the absence of time estimates the values shown below can be used in calculating a minimum optical density.

Suggested exposure times for eyewear design

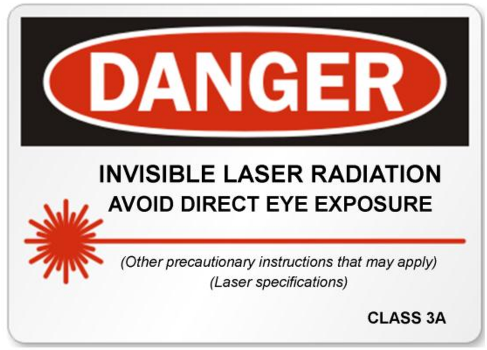
Wavelength (μm)	Intrabeam viewing (seconds)	Diffuse viewing (seconds)
0.2 to 0.4	30,000	30,000
0.4 to 0.7	0.25	600
0.7 to 1.4	10	600
1.4 to 1,000	10	10

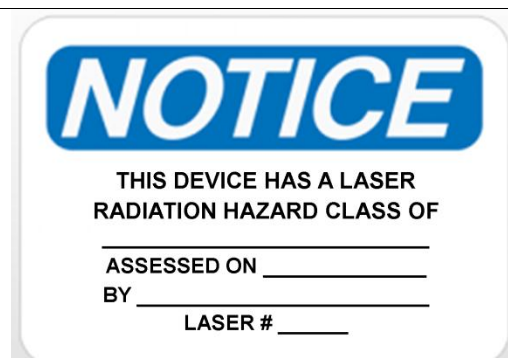
Determination of H_p and MPE is often a complex matter. Assistance in the determination of the optical density can be provided by the Laser Safety Officer and/or the manufacturers of the laser protective eyewear.

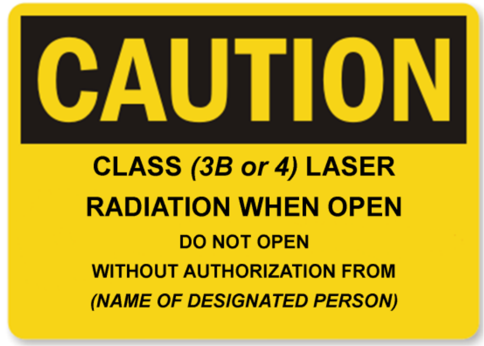
6.2 Laser signs and labels

Acceptable content for laser warning signs and labels is shown below. In most cases, commercial lasers will be properly labeled by the manufacturer. Signs are required for Class 3b and Class 4 lasers and laser systems and are recommended for Class 3a lasers and laser systems. All listed labels are required regardless of the operational hazard class. Laser radiation hazard warning signs and labels are available from the ES&H Section.

Sign Hazard class 3a Visible ≤ MPE	
Sign Hazard class 3a Visible > MPE	
Sign Hazard class 3a UV/IR ≤ MPE	

Sign Hazard class 3a UV/IR > MPE	

Sign Hazard class 3b *INVISIBLE precedes LASER for UV or IR radiations*	
Sign Hazard class 4 *INVISIBLE precedes LASER for UV or IR radiations*	
Label Classification Inventory	

Label Laser enclosure	
Label Laser fiber optic	

In a research environment, it is not unusual to encounter several lasers, laser systems or wavelengths being used in one location. This can complicate the provision of warning information since precautions may vary with operational conditions. In particular, there may be a variety laser eyewear for different situations. There are a number of options for posting enclosures.

- Have a sign for each laser. Only post those for lasers in use.
- List all lasers or wavelengths and have a means to indicate which are in use. Try to limit the number of listed lasers or wavelengths to five per sign.
- Indicate that multiple wavelengths may be in use and personnel who wish to enter must check with the laser operator.

6.3 Laser enclosures - It is a good idea to reduce the hazard class of a laser system by enclosing the beam path, especially for extended/repeated operations in a single location. Enclosure is in the best interest of the laser operator since it simplifies safety requirements and reduces the likelihood of damage to the laser set up.

Enclosures must be locked or interlocked in order to minimize the risk of inadvertent exposure. Labeling is also required, unless failsafe interlocks are used. The enclosure must be “tight” enough such that any escaping laser radiation is not at harmful levels. For class 4 systems, enclosures should be near-perfect since even non-specular reflections can be hazardous. Enclosures for class 3b systems may be constructed with less conservatism. Openings can often be allowed where the beam path requires multiple non-specular reflections.

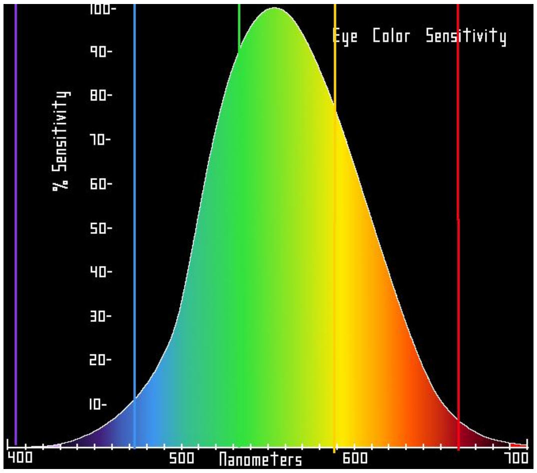
Radiations are often transported from lasers to their use locations via systems of optical fibers or piping with reflective surfaces. If the transported radiation levels are hazardous, then the rules for enclosure must also be applied to the transport system.

Where ready access to an operating laser or laser radiation is needed, the room in which the activity is taking place typically becomes the enclosure. It is often desirable to allow entry to and exit from laser rooms during laser operation. When this is done, care must be exercised to limit laser radiation levels at points of entry to the applicable Maximum Permissible Exposure (MPE). It should be kept in mind that laser rooms are subject to the same kinds of life safety requirements as other occupied spaces. This includes exiting, fire protection systems, and electrical safety.

When stable operation has been established, a laser is often put into a box so it is isolated from people. These boxes are most often constructed of aluminum. One side of the box is equipped with a piano hinge and threaded closures to serve as an access panel. The closures require a tool to open the panel. This qualifies as a "lock" for making up the enclosure. The access panel is labeled with a cautionary statement that the box contains hazardous levels of laser radiation and must only be opened upon authorization of the primary laser operator for the system. If hazardous levels of laser radiation are transmitted from the interior of the box to another location via fiber optics, they too are considered part of the enclosure.

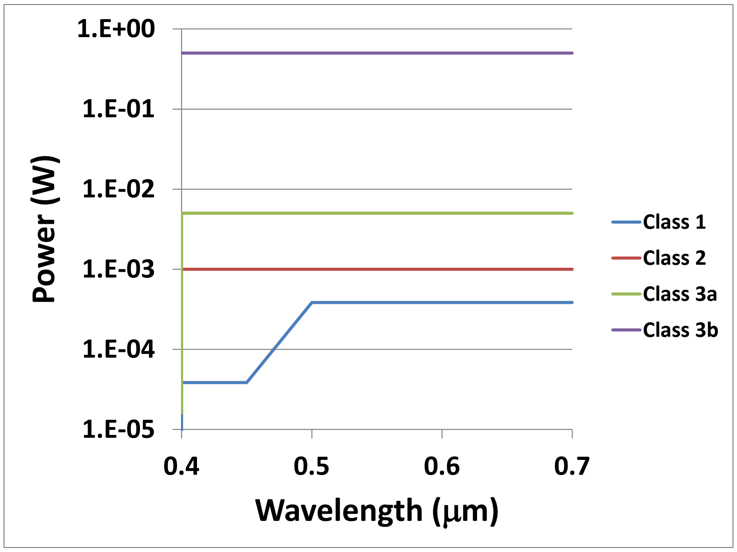
6.4 Laser pointers

6.4.1 Background **-** A laser pointer is a small portable laser intended to highlight something of interest by projecting a small spot of light. To be useful for this purpose, the wavelength of the laser light must lie within the visible portion of the electromagnetic spectrum. The range is 0.4 to 0.7 μm with the peak sensitivity around 0.56 μm.



Human visual sensitivity.
Image from [http://en.wikipedia.org/wiki/Color_vision.](http://en.wikipedia.org/wiki/Color_vision)

That is why green lasers (0.532 μm) appear much brighter than red lasers (0.670 μm) at the same power. Since the hazard class limits are essentially independent of wavelength, green is in principle the best choice from a hazard-benefit standpoint.



Hazard class limits from ANSI Z136.1-2007

On the other hand, laser pointers that emit radiation outside the visible spectrum present a hazard without adding to the visibility of the spot. Unfortunately, most non-red laser pointers are capable of emitting non-visible IR radiation if improperly manufactured. These devices typically employ a near-IR laser that is wavelength-shifted into the visible portion of the spectrum using a combination of crystals and dielectric coatings (see http://en.wikipedia.org/wiki/Laser_pointer). The near-IR radiation is supposed to be blocked from exiting the laser via the addition of an IR filter. However, the filter is sometimes absent, either accidentally as a result of poor engineering/manufacturing or intentionally as a means of maximizing the total laser output.

The FDA does not have a specific standard for laser pointers, but regulates them as "laser products for pointing and demonstration purposes." (see http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/HomeBusinessandEntertainment/LaserProductsandInstruments/ucm116373.htm). Such devices are limited to CDRH class 3a or IEC1 Class 3R. For CW visible wavelengths this corresponds to a power of 5 mW. Limits for "pointing and demonstration" lasers can also be determined for invisible wavelength or pulsed radiations. Where multiple wavelengths and/or modulations are simultaneously emitted, compliance can be evaluated using the following expression.

$$\sum_{i=0}^{n} \frac{\emptyset_i}{AEL_i} \leq 1$$

Where,

Φ – Power emitted in the form of radiation (W)

AEL – Accessible emission limit for class 3a (W)

The FDA requires warning labels on Class 3a and 3b products. Class 3b products must also have a key switch and connector for remote interlock. Below are sample labels with precautionary statements and hazard classes.

This is an example of a label that would be appropriate for class 2 laser pointers. However, labeling is optional for class 2 lasers.

Label for class 3a laser pointers where $E \leq 2.5\ mW/cm^2$.

Label for class 3a laser pointers where $E > 2.5\ mW/cm^2$.
This is the typical case for class 3a laser pointers.

At the time this document was written, it was fairly easy to purchase laser products that were sold and/or configured as laser pointers, with outputs greatly exceeding hazard class 3a and/or much of their output was being emitted in the IR portion of the spectrum. The most common kinds of devices were emitting at 0.405, 0.532 or 0.650 µm. A quick check revealed that the higher power laser pointers could be purchased on the internet at a modest cost (results below).

Power 405 nm 532 nm 650 nm	Exceeds class 3a output by	Lowest price with multiple searches	Lowest prices with 1-2 searches
50 mW	10X	$10	$15
200 mW	40X	$20	$30
1000 mW	200X	$200	$300

Besides having a low price, the cost seems fairly independent of wavelength. In addition, the costs for 50 - 200 mW laser pointers are comparable to those for ≤5 mW FDA-compliant laser pointers.

6.4.2 Recommendations - The following recommendations apply to laser pointers that will be used to highlight something of interest by projecting a small spot of light. These devices should be limited to visible wavelength hazard classes 2 and 3a. As a general rule, the beam should never be pointed at others, vehicles, or shiny objects. In addition, no one should be allowed to stare into the beam.

Laser pointers in hazard classes 3b or 4, and/or those with substantial radiation in non-visible wavelengths (<0.4 μm or >0.7 μm) should not be used for routine visual highlighting purposes. Such devices are subject to the numerous laser controls including operator training and eye exams. Though these lasers are not useful as pointers, they may be OK for qualified laser operators in well-controlled research and technical environments.

6.4.2.1 Best choice for a laser pointer **-** The most practical and acceptably safe laser pointer emits at 0.532 μm (only) and has a power of 1 mW or less. This wavelength is near the peak of human visual sensitivity, so it only takes a small amount of power to produce a bright spot. On the other hand, the risk of eye injury is no greater than that for other wavelengths in the visible range. The 1 mW power level corresponds to a hazard class of 2.

6.4.2.2 Acceptable choice for a laser pointer **-** The wavelength of the laser pointer must be in the visible portion of the electromagnetic spectrum (0.4-0.7 μm) and the output must not exceed 5 mW. This corresponds to hazard class 3a. The nearer the wavelength is to 0.560 μm, the easier it will be to see the beam. The device must have an appropriate class 3a laser warning label.

6.4.2.3 Unacceptable choices for a laser pointer

- Any device with an output exceeding hazard class 3a is not acceptable for use as a laser pointer. This includes CW visible wavelength lasers (0.4-0.7 μm) exceeding 5 mW. Use of such a device requires that the operator receive laser safety training and a laser safety eye exam. Additional controls may apply.
- Any device with invisible radiation (<0.4 μm or >0.7 μm) that exceed hazard class 1 is not acceptable for use as a laser pointer. This is because potentially-exposed persons would have no way of knowing they are being irradiated by a laser. EXCEPTION: if the device emits visible radiation of sufficient intensity to

discourage staring into the beam, then it is OK to use a 3a combined output limit. A visible output of 1 mW is certainly sufficient to deter staring. In fact, this is the limit for hazard class 2. However, "sufficient visible brightness" may need to be subjectively evaluated since outputs below 1 mW may also be adequate to deter staring into the beam.

6.4.3 Laser pointer testing - The ES&H Section has instrumentation that can be used to measure visible and near IR wavelengths emitted from lasers. The laser power meter measures the power in both wavelength bands, then a filter is used to block the visible wavelengths. By combining these two values the power, in each band can be obtained. It should be noted that we have found laser pointers where the total output greatly exceeds labeled values, as well as laser pointers where the IR output greatly exceeds the visible output. As discussed above, these are very good reasons to reject a laser pointer for its primary intended purpose of highlighting items with a visible dot.

6.5 Revised hazard classification system

In 2001, European and international safety communities revised their laser hazard classification systems by adding classes 1M, 2M, and 3R. The "M" means the beam presents the same hazard as class 1 and class 2, unless collecting optics are used (i.e., the beam is magnified), in which case the hazard is increased. Class 3R is essentially the same as the old class 3a. Classes 1, 2, 3b (new "3B") and 4 were unchanged.

Though ANSI adopted this revised system in Z136.1- 2007, DOE contractors are required to comply with Z136.1-2000 which uses the old system. In addition, the current FDA standard for light-emitting products [21CFR1040.10(b)] also makes use of the older system.

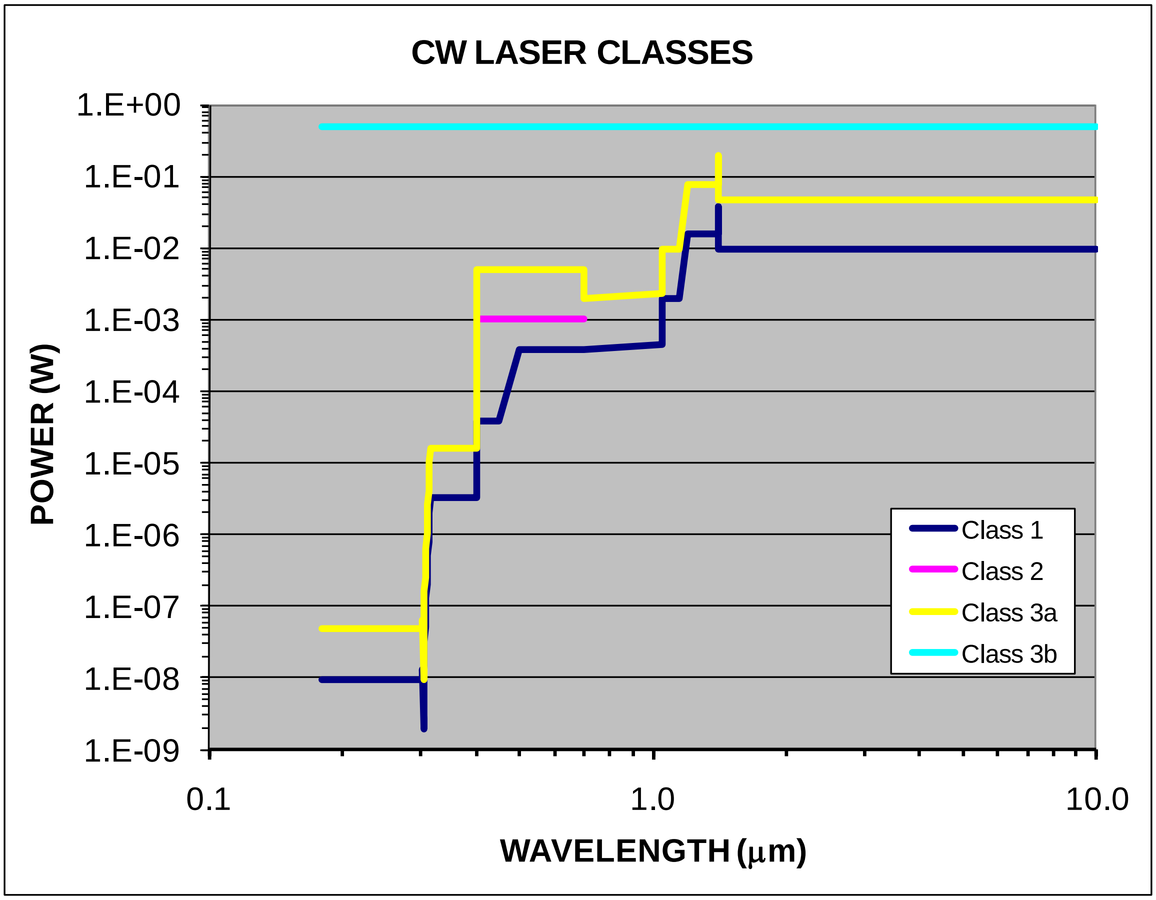
6.6 Tables and charts

ANSI Z136.1-2000
Required controls
(including section references)

Control #	Section #	Control	1	2	3a	3b	4	Engineering control	Administrative or procedural control
1	4.3.1	Protective housing	X	X	X	X	X	X	
2	4.3.1.1	Without protective housing	LSO	LSO	LSO	LSO	LSO	X	
3	4.3.2	Interlocks on protective housing	Δ	Δ	Δ	X	X	X	
4	4.3.3	Service access panel	Δ	Δ	Δ	X	X	X	
5	4.3.4	Key control				*	X	X	
6	4.3.5.1	Viewing portals		MPE	MPE	MPE	MPE	X	
7	4.3.5.2	Collecting optics	MPE	MPE	MPE	MPE	MPE	X	
8	4.3.6.1	Totally open beam path				NHZ	NHZ	X	
9	4.3.6.2	Limited open beam path				NHZ	NHZ	X	
10	4.3.6.3	Enclosed beam path	if no H	if no H	if no H	if no H	if no H	X	
11	4.3.7	Remote interlock connector				*	X	X	
12	4.3.8	Beam stop or attenuator				*	X	X	
13	4.3.9.4	Activation warning systems				*	X	X	
14	4.3.9.1	Emission delay					X	X	
15	4.3.10	Indoor laser controlled area				X	X	X	
16	4.3.10.1	Class 3b indoor laser controlled area				X		X	
17	4.3.10.2	Class 4 indoor laser controlled area					X	X	
18	4.3.11	Laser outdoor controls				X	X	X	
19	4.3.11.2	Laser in navigable airspace			*	*	*	X	
20	4.3.12	Temporary laser controlled area	Δ MPE	Δ MPE	Δ MPE			X	
21	4.3.13	Remote firing and monitoring					*	X	
22	4.3.14	Labels	X	X	X	X	X	X	
23	4.7	Labels	X	X	X	X	X	X	
24	4.3.9	Area posting			*	X	X	X	
25	4.4.1	Standard operating procedures				*	X		X
26	4.4.2	Output emission limitations			LSO	LSO	LSO		X
27	4.4.3	Education and training		*	*	X	X		X
28	4.4.4	Authorized personnel				X	X		X
29	4.4.5	Alignment procedures		X	X	X	X		X
30	4.6	Protective equipment				*	X		X
31	4.4.6	Spectator				*	X		X
32	4.4.7	Service personnel	Δ	Δ	Δ	X	X		X
33	4.5.1	Demonstration with general public	inv MPE	X	X	X	X		X
34	4.5.2	Laser optical fiber systems	MPE	MPE	MPE	X	X		X
35	4.5.3	Laser robotic installations				X	X		X
36	4.6.2	Eye protection				* MPE	X		X
37	4.6.3	Protective windows				NHZ	NHZ		X
38	4.6.4	Protective barriers and curtains				*	*		X
39	4.6.6	Skin protection				MPE	MPE		X
40	4.6.7	Other protective equipment	LSO	LSO	LSO	LSO	LSO		X
41	4.7	Warning signs and labels (designs)		*	*	NHZ	NHZ		X
42	4.4.7	Service and repairs	LSO	LSO	LSO	LSO	LSO		X
43	4.1.2	Modifications and laser systems	LSO	LSO	LSO	LSO	LSO		X

X	Shall
*	Should
Δ	Shall if enclosed 3b or 4
MPE	Shall if MPE exceeded
NHZ	Shall, requires NHZ analysis
if no H	Shall, if no housing
LSO	LSO discretion

Maximum continuous wave laser power
as a function of wavelength and hazard class
(Interpreted from ANSI Z136.1-2000 values for MPE)



Power to reach ocular MPE
as a function of wavelength and exposure time
(Interpreted from ANSI Z136.1-2000 values for MPE)